

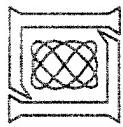
Document And Report Documentation Page Submitted as edoc_1075485963

Report Documentation Page		<i>Form Approved OMB No. 0704-0188</i>	
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1. REPORT DATE 10 MAR 2003	2. REPORT TYPE N/A	3. DATES COVERED -	
4. TITLE AND SUBTITLE Robust MIMO Wireless Communications in the Presence of Interference Using Ad Hoc Antenna Arrays		5a. CONTRACT NUMBER	
		5b. GRANT NUMBER	
		5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)		5d. PROJECT NUMBER	
		5e. TASK NUMBER	
		5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) MIT Lincoln Laboratory		8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S)	
		11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release, distribution unlimited			
13. SUPPLEMENTARY NOTES Also see: ADM001520 , The original document contains color images.			
14. ABSTRACT			
15. SUBJECT TERMS			
16. SECURITY CLASSIFICATION OF:	17.	18.	19a. NAME OF RESPONSIBLE

a. REPORT unclassified	b. ABSTRACT unclassified	c. THIS PAGE unclassified	LIMITATION OF ABSTRACT UU	NUMBER OF PAGES 37	PERSON Patricia Mawby, EM 1438 PHONE:(703) 767-9038 EMAIL:pmawby@dtic.mil
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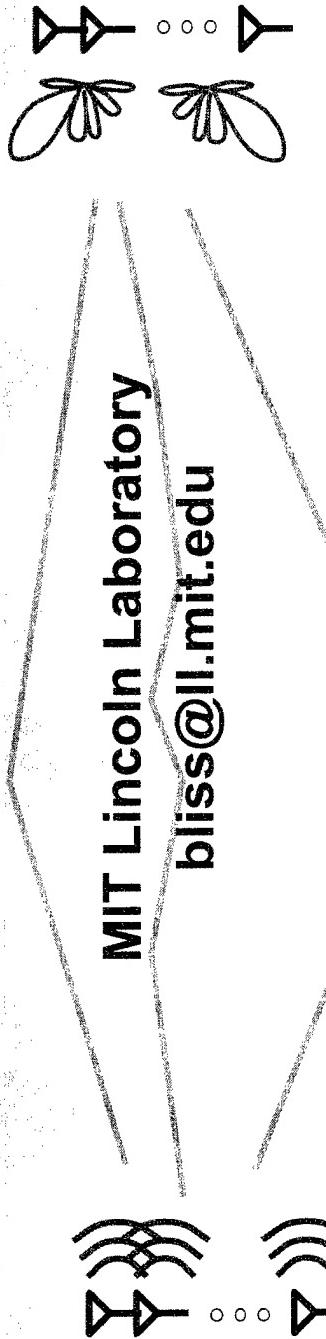
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Robust MIMO Wireless Communication in the Presence of Interference Using Ad Hoc Antenna Arrays

20040317 147

Dr. Daniel W. Bliss
& Amanda M. Chan

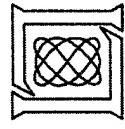
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This work was sponsored by the U.S. Air Force under Air Force contract F19628000-C-0002. Opinions, interpretations, conclusions, and recommendations are those of the authors and are not necessarily endorsed by the United States Government.

mimoASAP-1
bliss

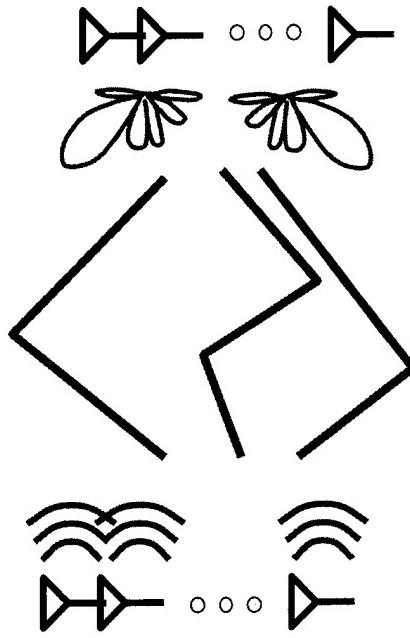
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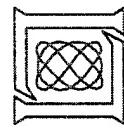


Topics

MIMO Communication

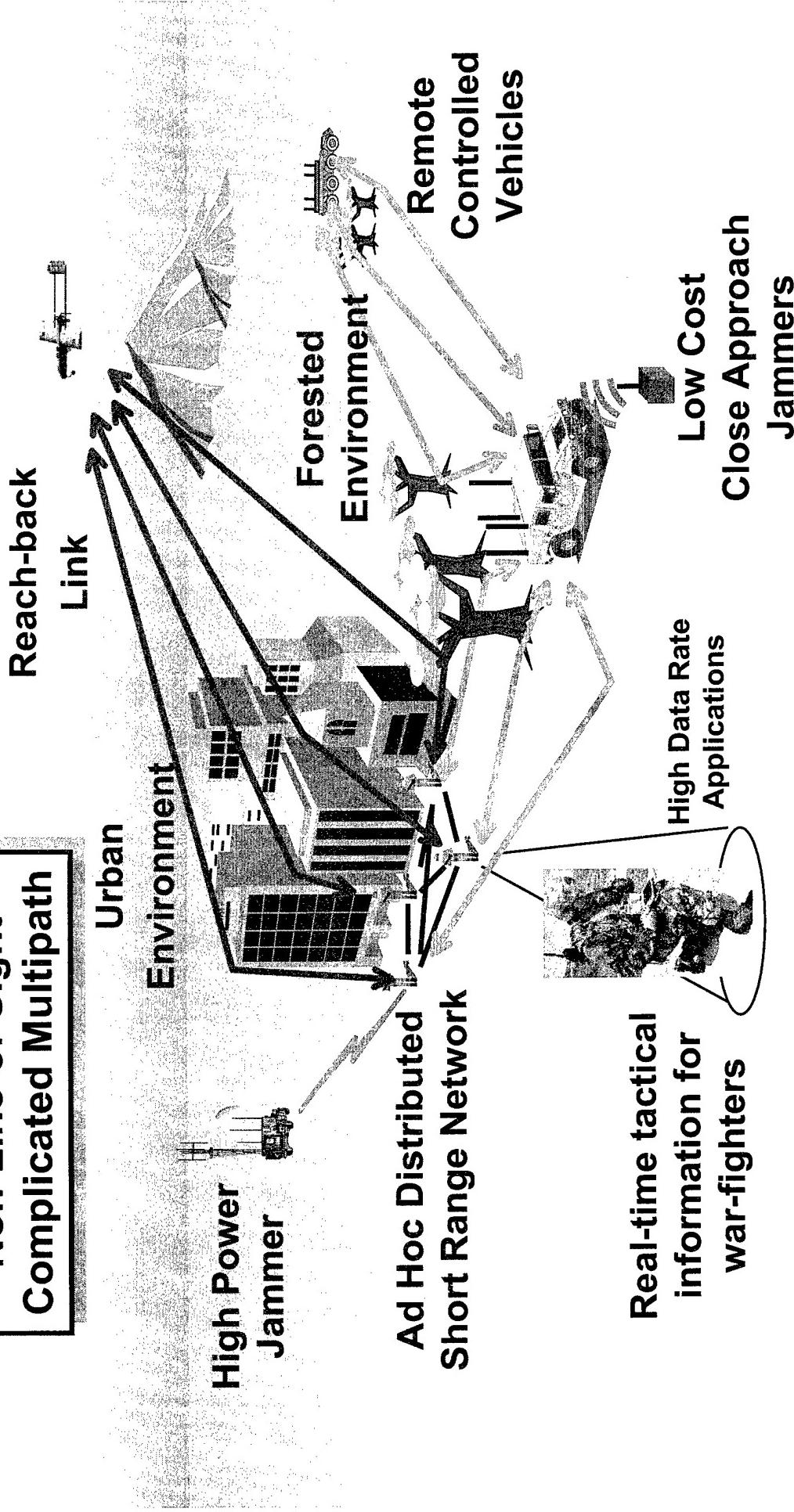
- **Introduction**
 - Military wireless communication
 - MIMO definition
 - Ad hoc antenna networks
- **MIMO Theory**
- **Phenomenology**
- **Receiver**

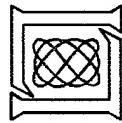




Advanced Military Wireless Communications

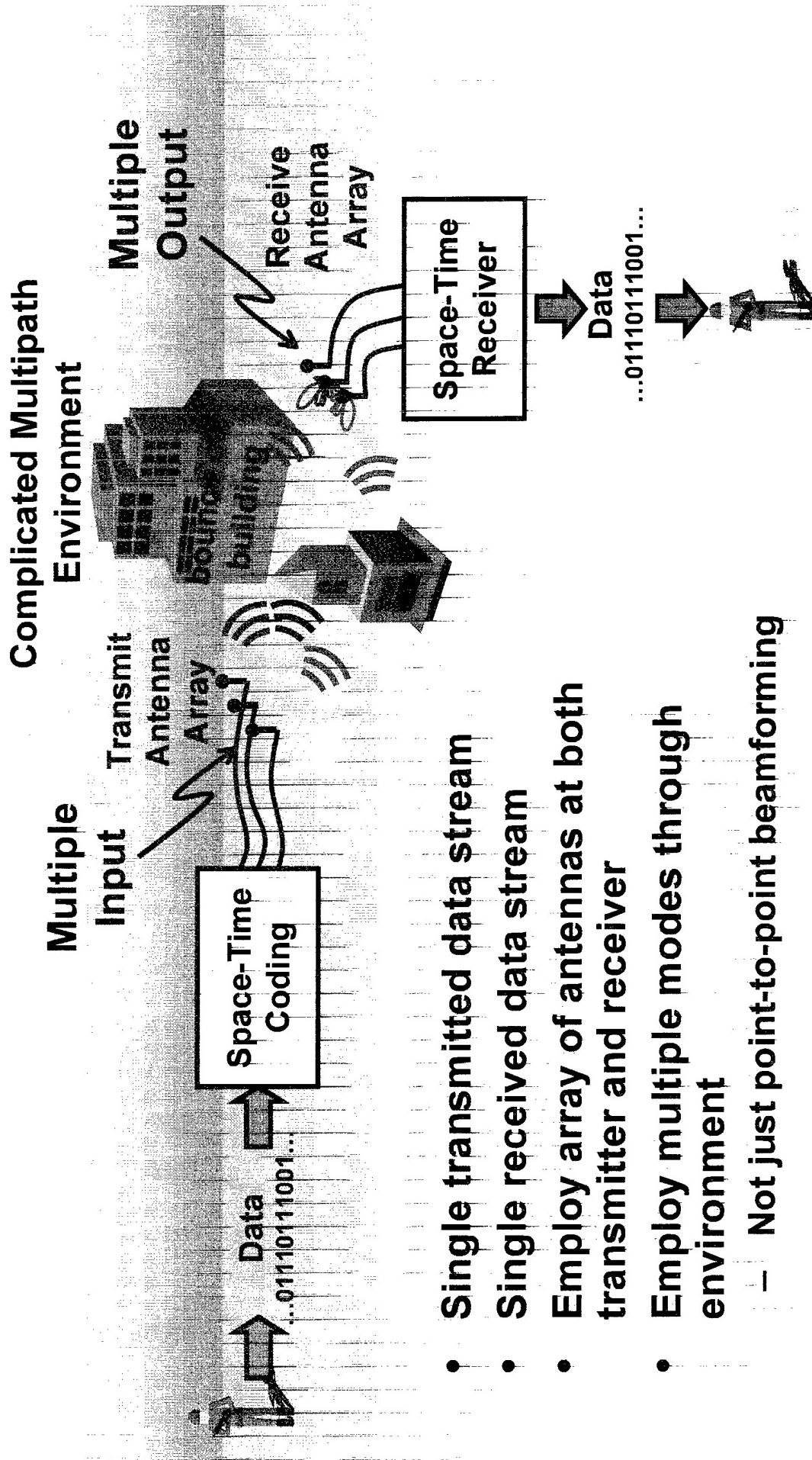
**Non-Line-of-Sight
Complicated Multipath**

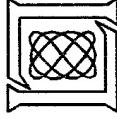




MIMO Communication

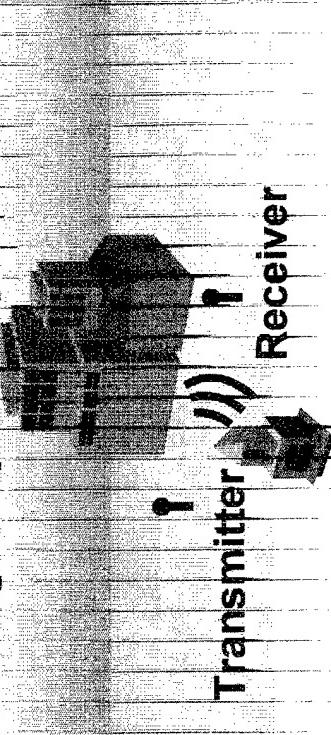
Multiple-Input Multiple-Output





Advantages of MIMO Communication

SISO Communication Single-Input Single-Output



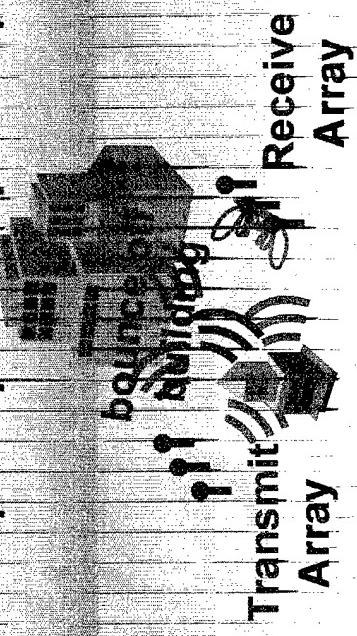
- Coherent receive beamforming

- Gain

- Jammer mitigation

Transmitter Receiver

MIMO Communication Multiple-Input Multiple-Output

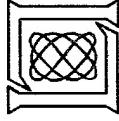


- Enables high spectral efficiency

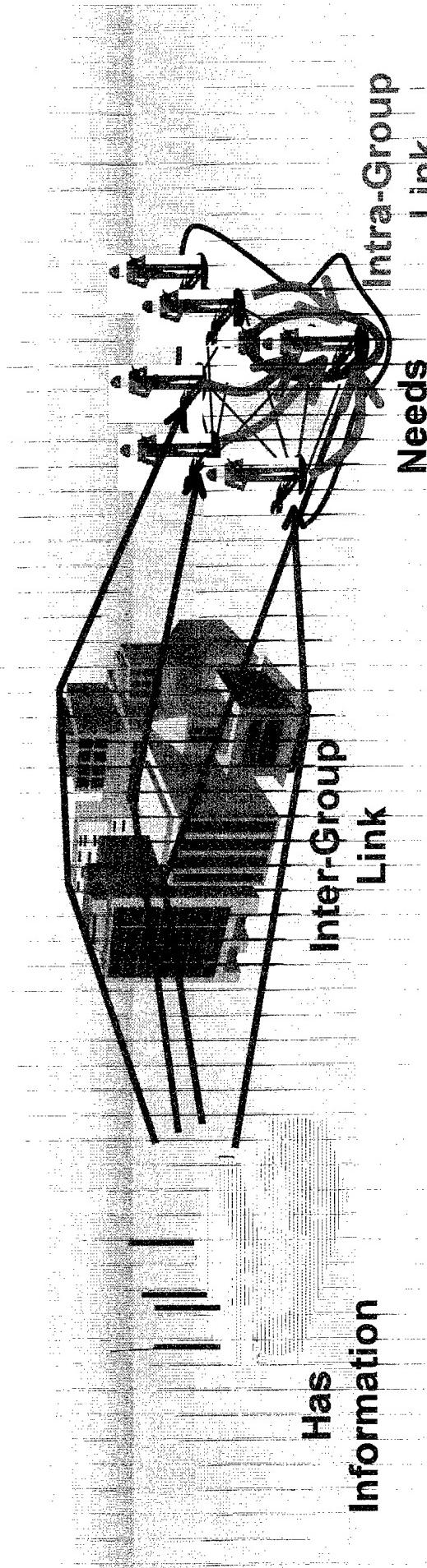
- Enables high data rates given

- limited bandwidths

- Low duty cycle communication



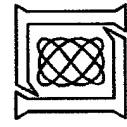
Distributed Ad Hoc Antenna Arrays Multiple-Input Multiple-Output



- Single transmit data stream
- Single received data stream
- Employ users as antenna array
 - Coherently process received signal
- Use local network to move distributed data to/from interested user

Issues

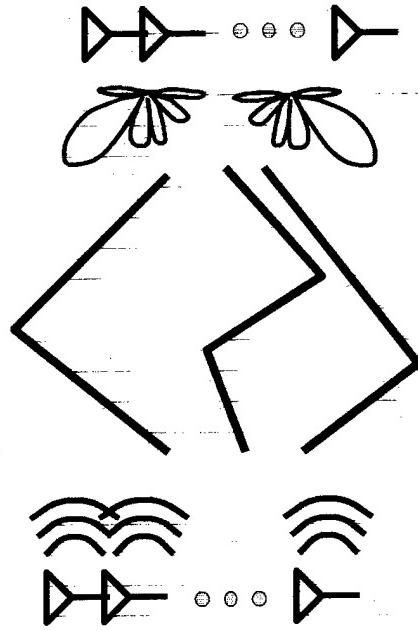
- Local networking
- Relative local oscillator errors

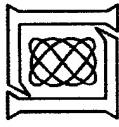


Topics

MIMO Communication

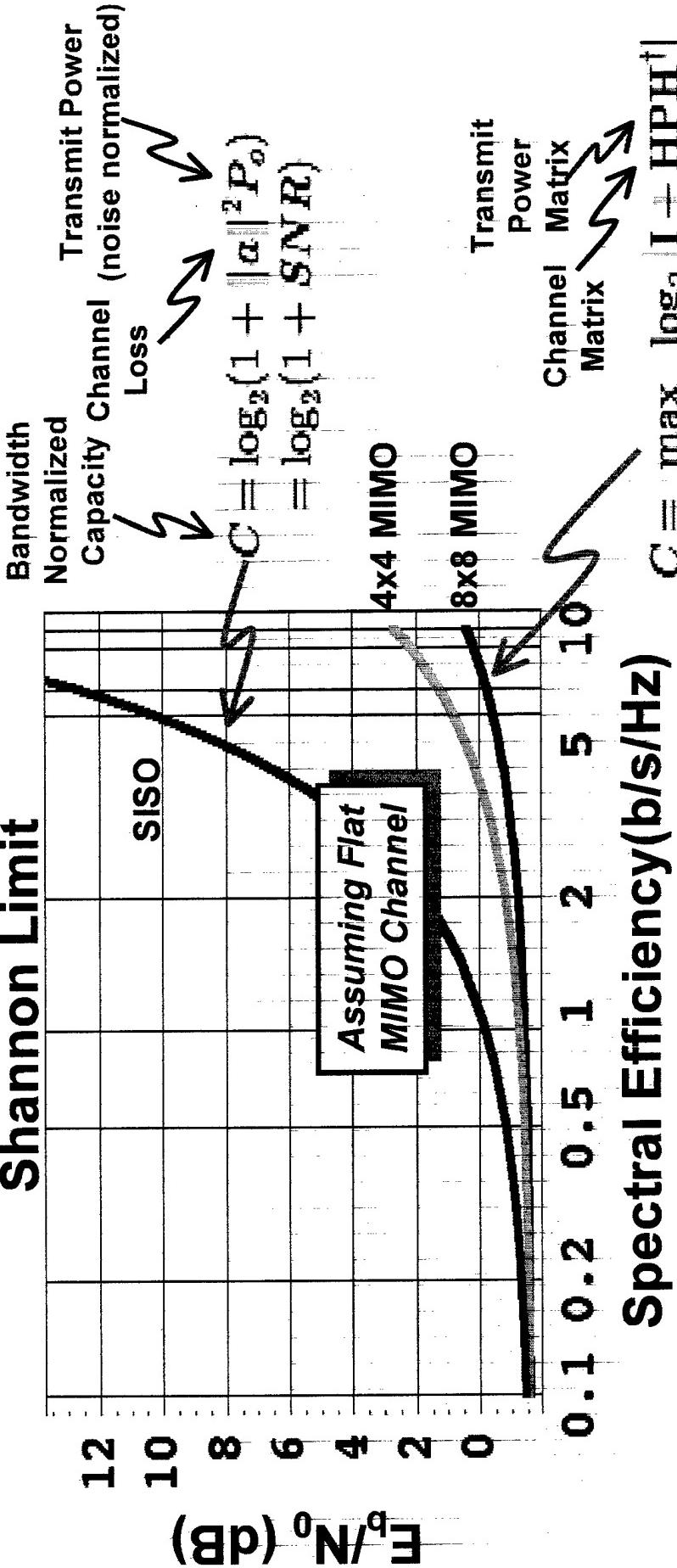
- Introduction
- MIMO Theory
 - Capacity
 - Phenomenology
 - Interference Mitigation
- Space-Time Coding
- Phenomenology
- Receiver





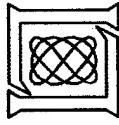
MIMO Capacity Bound

Shannon Limit



- MIMO bound follows different theoretical limit
- Divide total energy amongst transmitters avoiding compressive regime of SISO Shannon limit

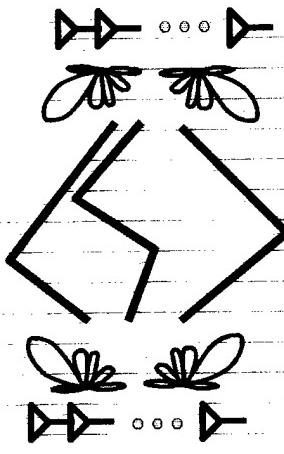
Determinant



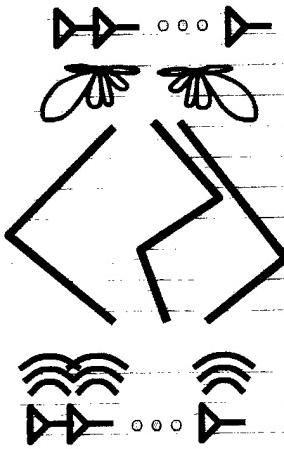
MIMO Channel Knowledge

Channel knowledge affects MIMO capacity and coding

Informed Transmitter



Uninformed Transmitter



Transmitter
Channel
Knowledge

Channel
Capacity
(b/s/Hz)

$$C_T = \max_{\text{tr}\{\mathbf{P}\} = P_o} \log_2 |\mathbf{I} + \mathbf{H} \mathbf{P} \mathbf{H}^\dagger|$$

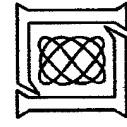
Determinant Power Matrix
(noise-normalized)

Total Power
(noise-normalized)

$$C_{UT} = \log_2 \left| \mathbf{I} + \frac{P_o}{n_{Tx}} \mathbf{H} \mathbf{H}^\dagger \right|$$

Number
of Transmitters

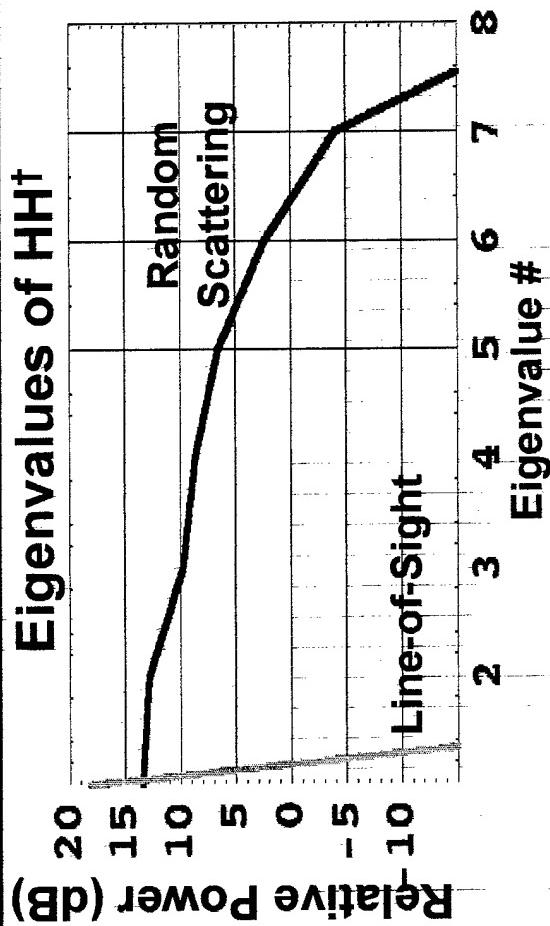
Channel
Matrix



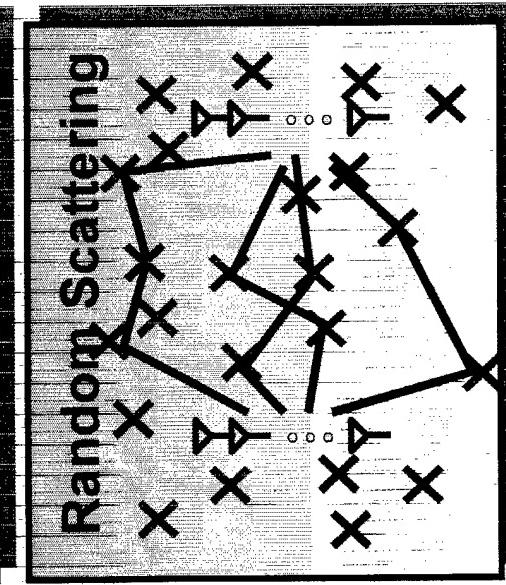
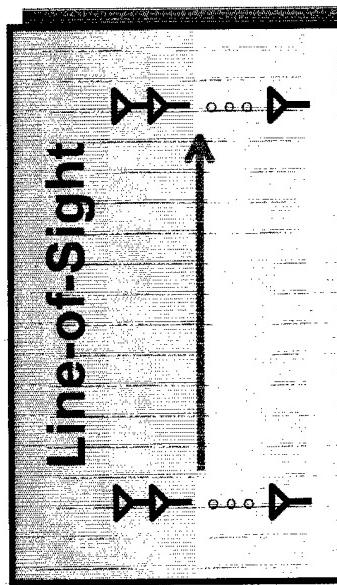
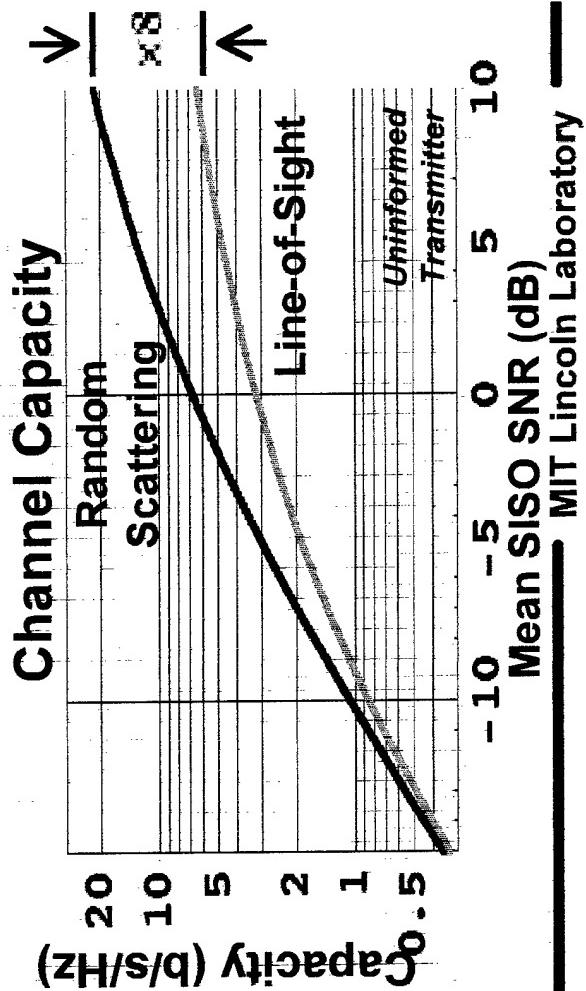
Channel Matrix 8 x 8 MIMO Example

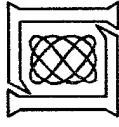
Channel matrix, H , contains complex attenuation between each transmit and receive antenna

Eigenvalues of HH^\dagger

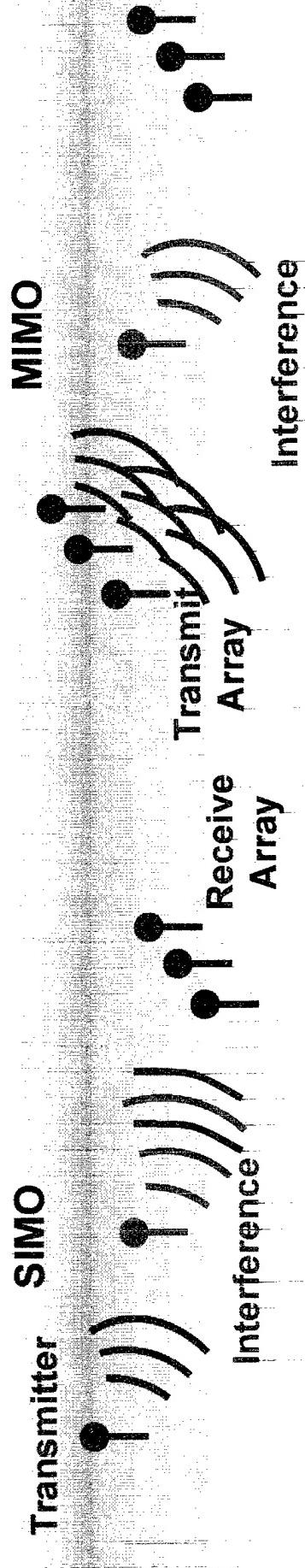


Channel Capacity

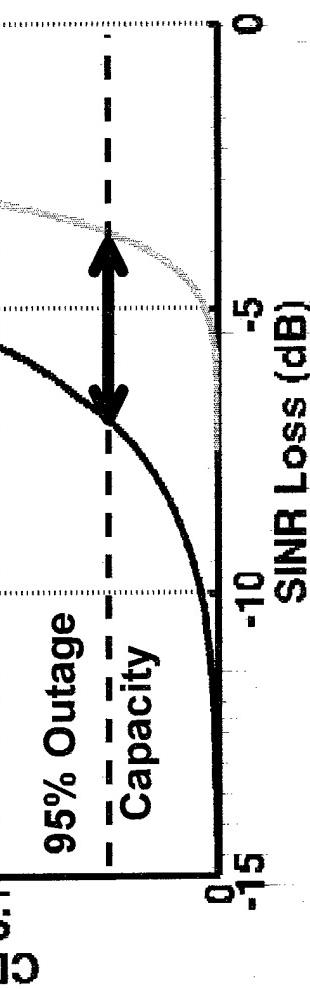




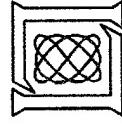
Jammer Mitigation & Avoidance SINR Loss



- Adaptive performance in the presence of Jammer
- MIMO has better outage capacity performance

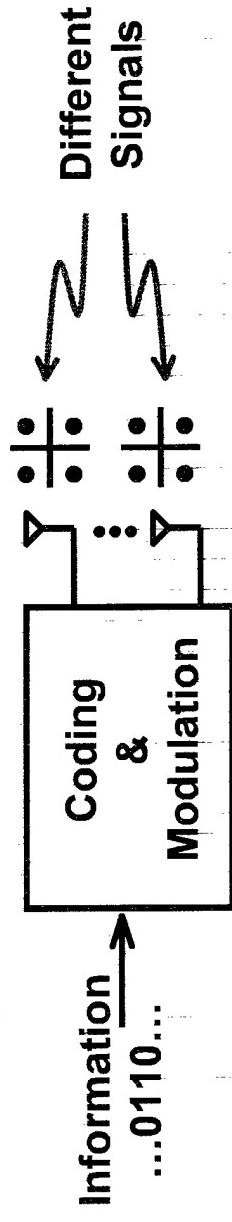


- Assumptions
 - Single high power jammer
 - I.I.D. random Gaussian channel
 - MIMO uninformed transmitter



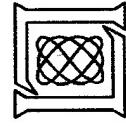
Space-Time Coding

- Space-time coding converts information bits to waveform distributed amongst antennas



- Space-time coding analogous to conventional (SISO) coding approaches
 - Trellis
 - Low density parity check
 - Turbo

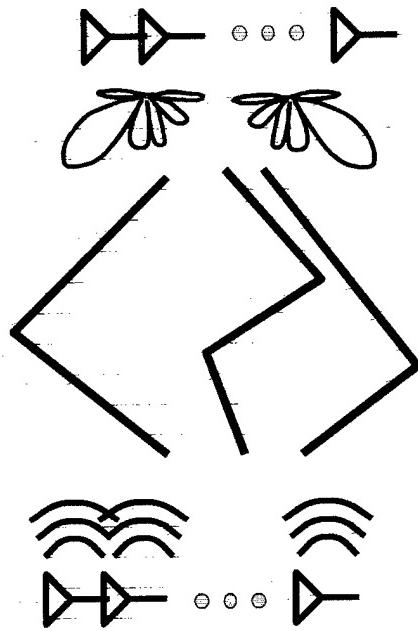


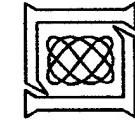


Topics

MIMO Communication

- Introduction
- MIMO Theory
- Phenomenology
 - Experimental setup
 - Phenomenology
- Receiver



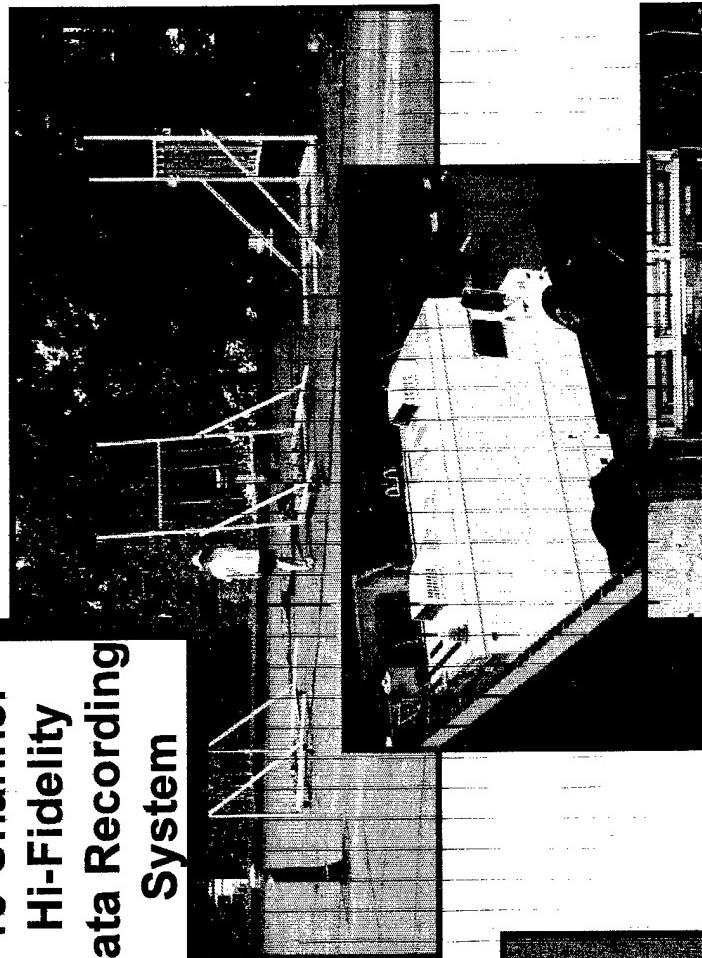


MIMO Experiment

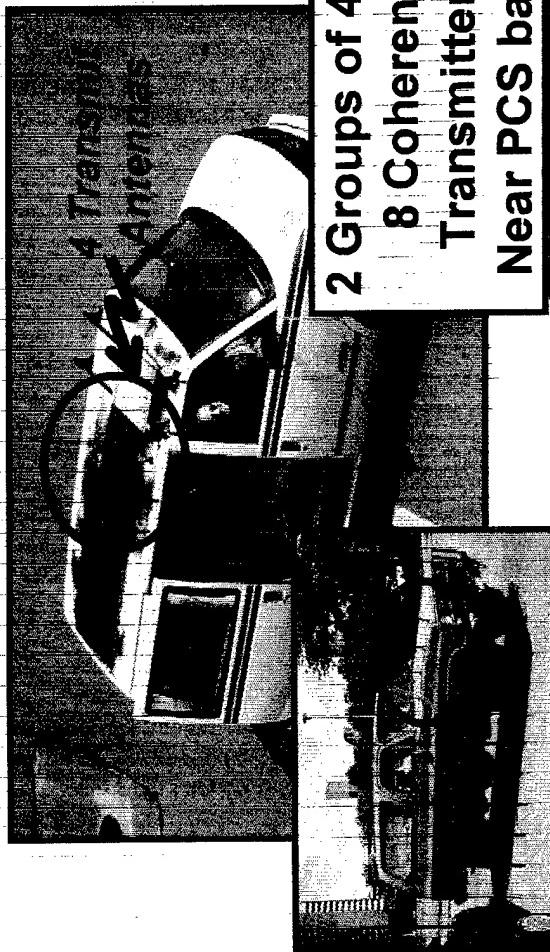
Summer 2002

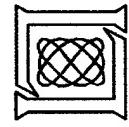
- Investigate channel phenomenology
- Study space-time coding
- Explore transmitter coherence requirements
- Demonstrate robustness to Jamming
 - Cochannel interference

**16-Channel
Hi-Fidelity
Data Recording
System**

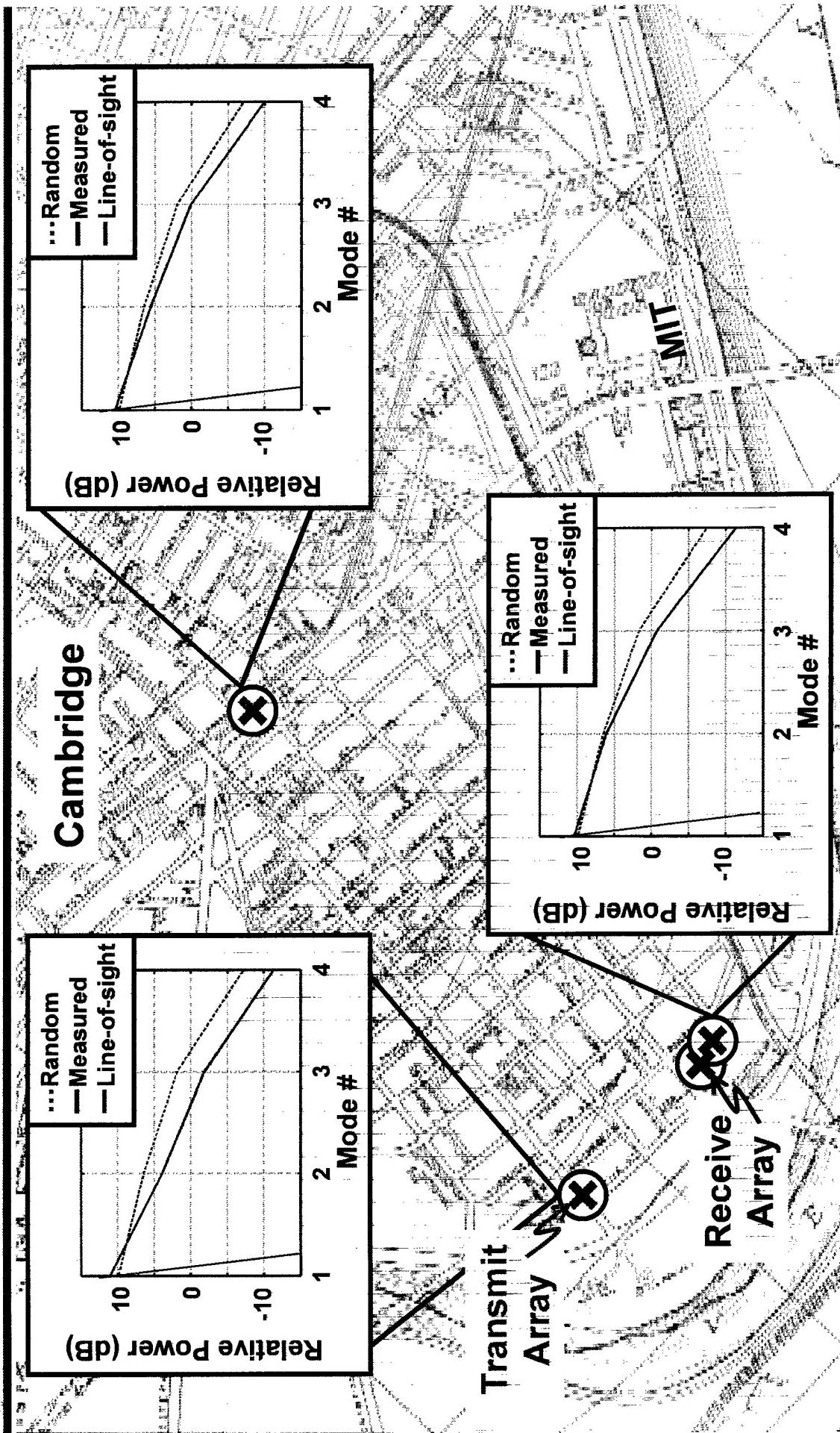


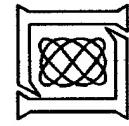
**2 Groups of 4, or
8 Coherent
Transmitters
Near PCS band**





Channel Modes Experimental Results

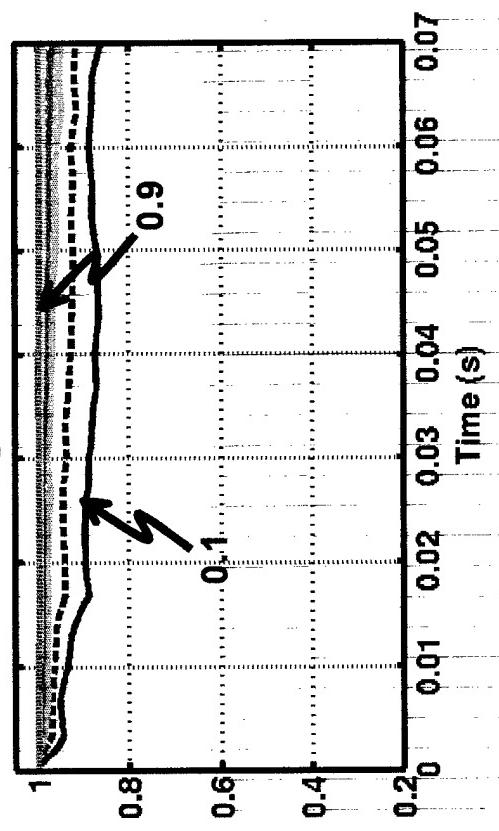




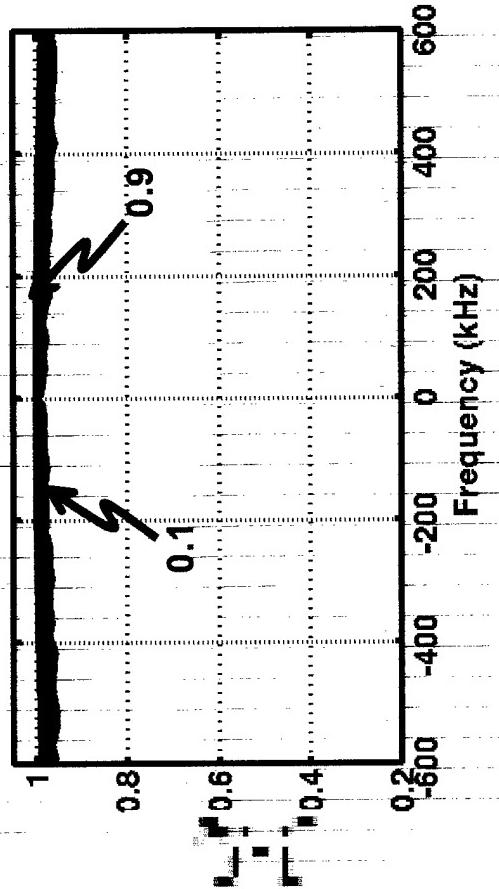
Channel Stationarity

CDF's of Power Weighted Mean $\cos^2\theta_n$

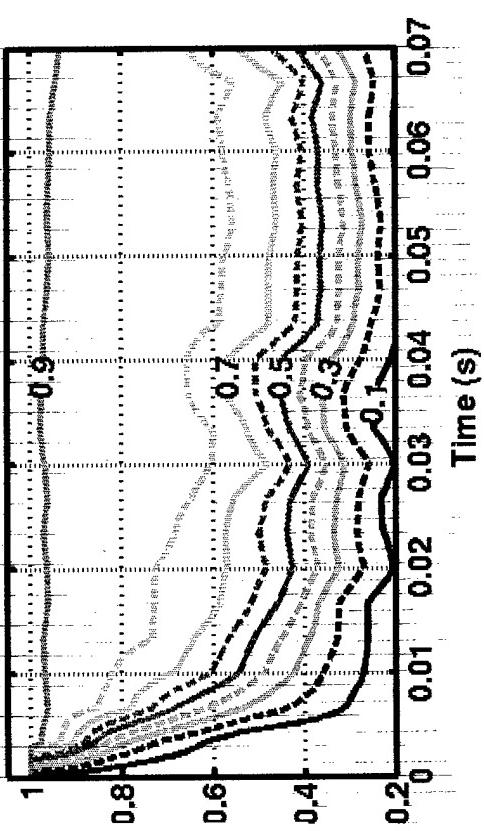
Stationary Transmitter



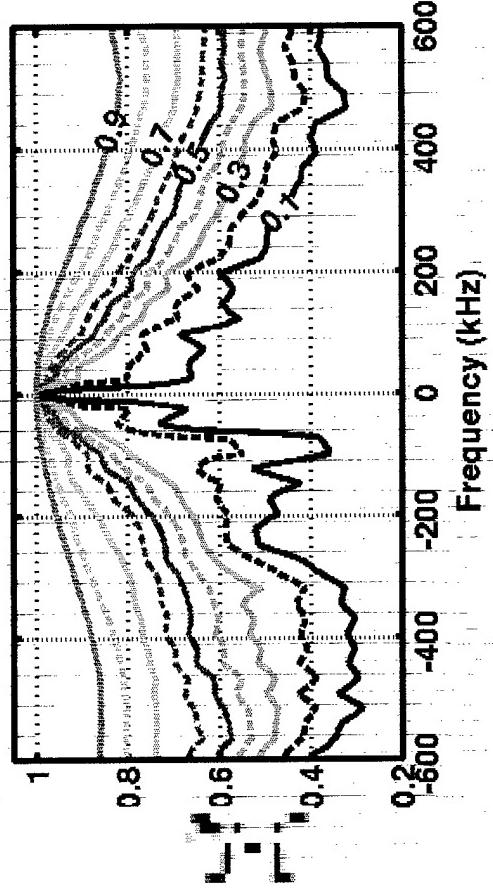
Indoor



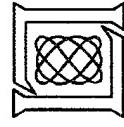
Moving Transmitter (5-10 m/s)



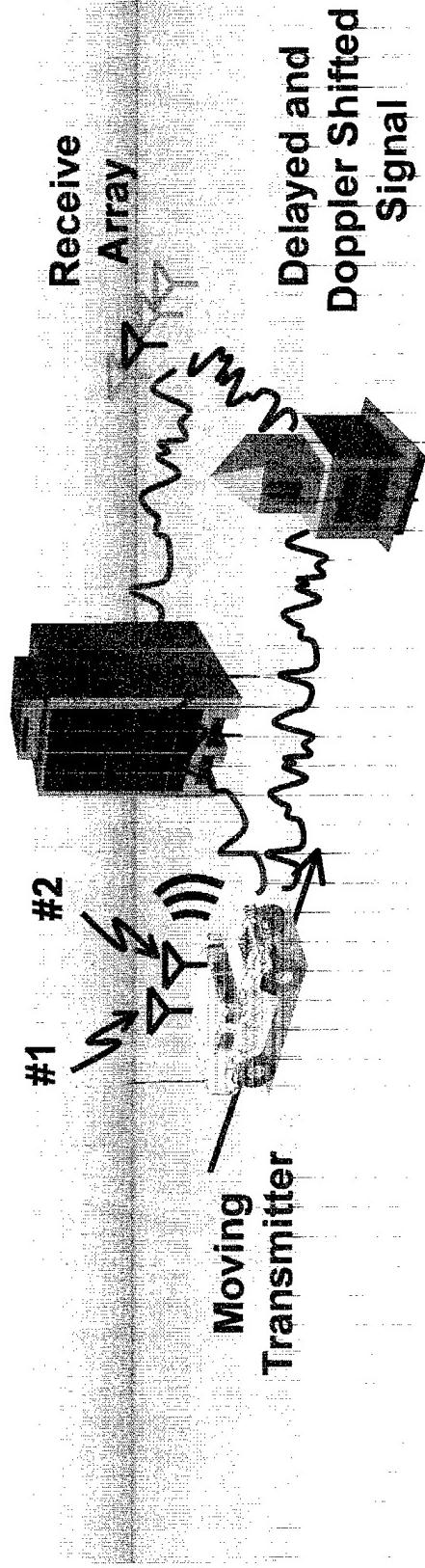
Outdoor



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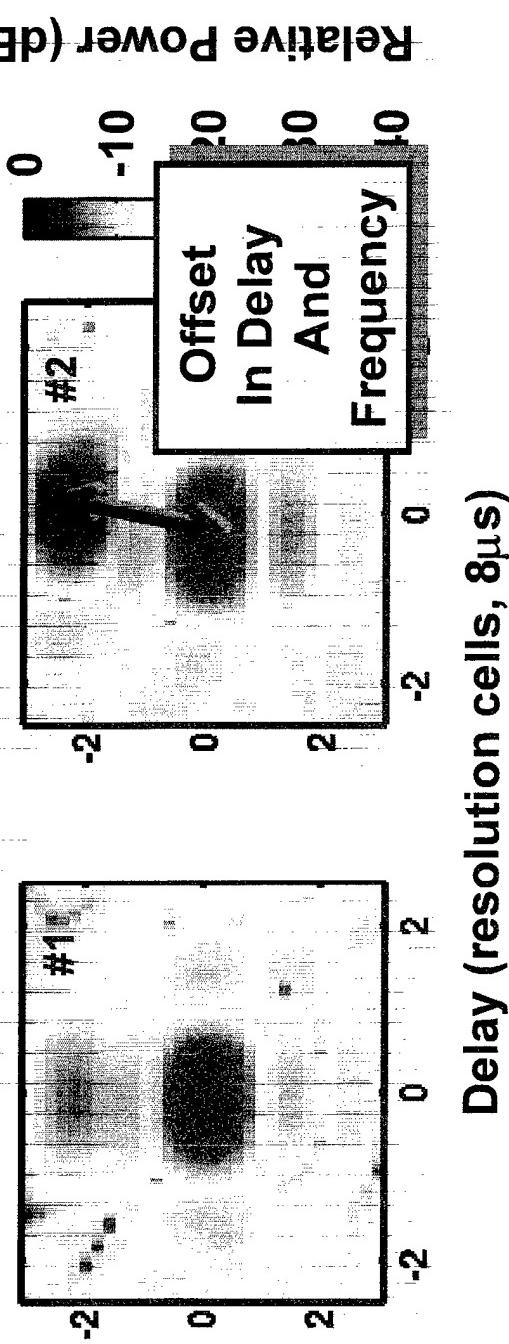


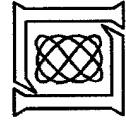
Delay-Frequency Correlations Experimental Data



(resolution cells, 60Hz)
Frequency Offset

Time-Frequency Pulse Response

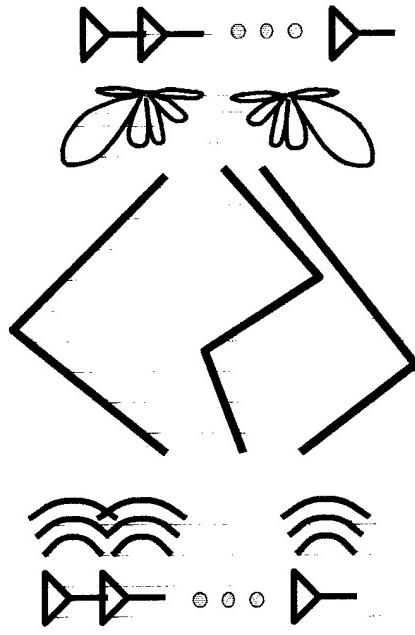




Topics

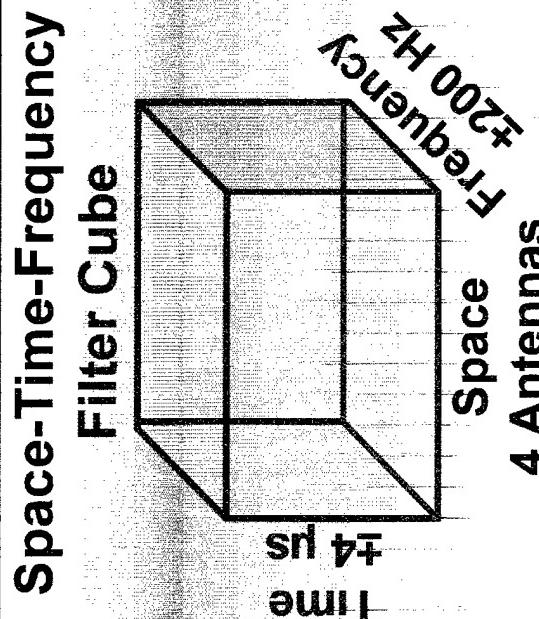
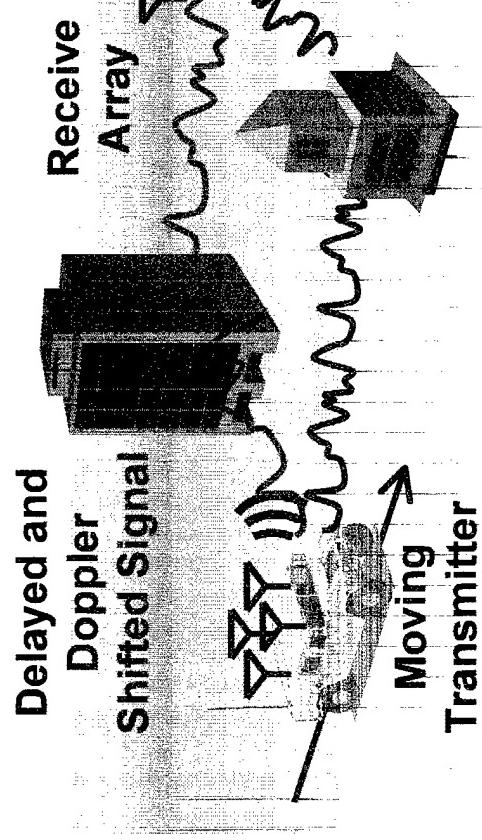
MIMO Communication

- Introduction
- MIMO Theory
- Phenomenology
- Receiver
 - Space-time-frequency adaptive processing
 - Multiuser detection
 - MCMUD
- Experimental performance

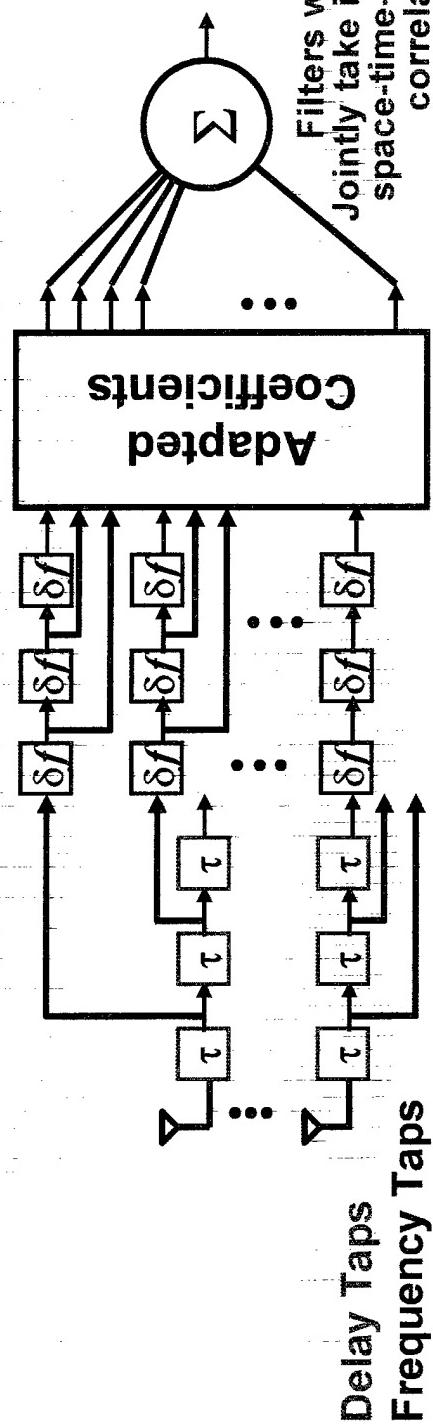


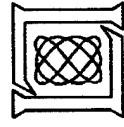


Adaptive Beamforming in Multipath

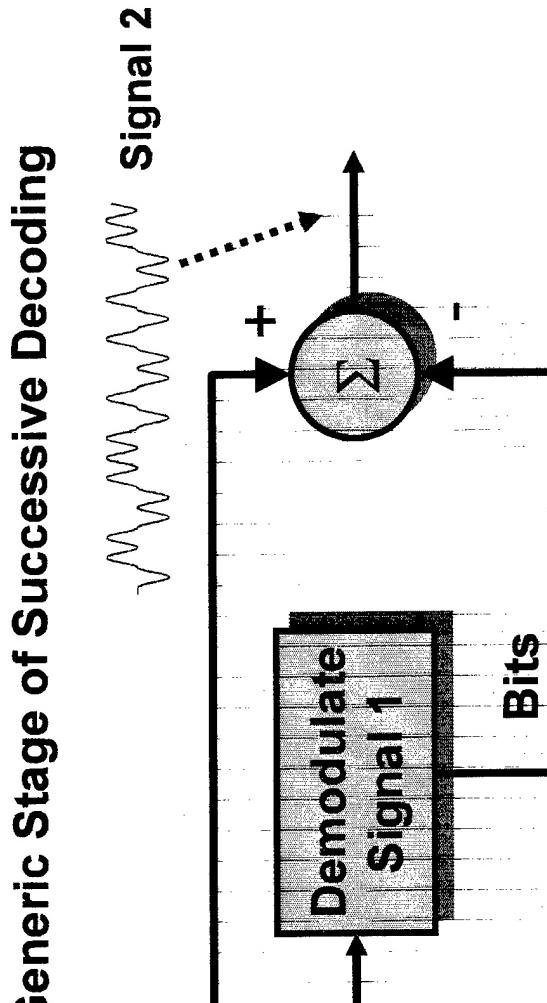
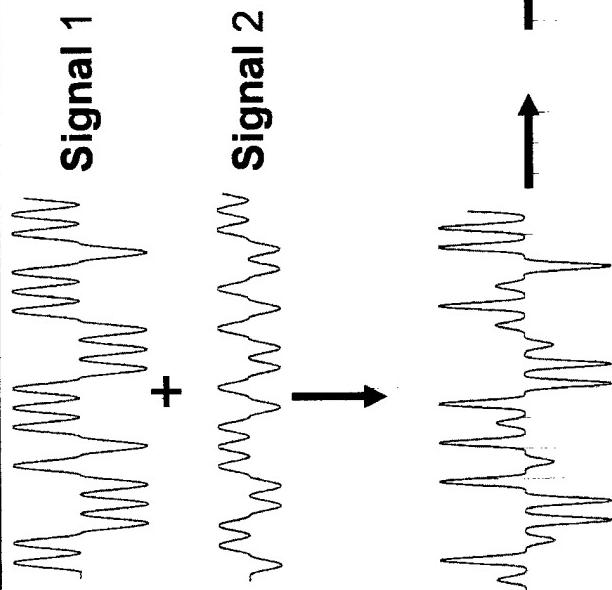


Space-Time-Frequency Adaptive Processing

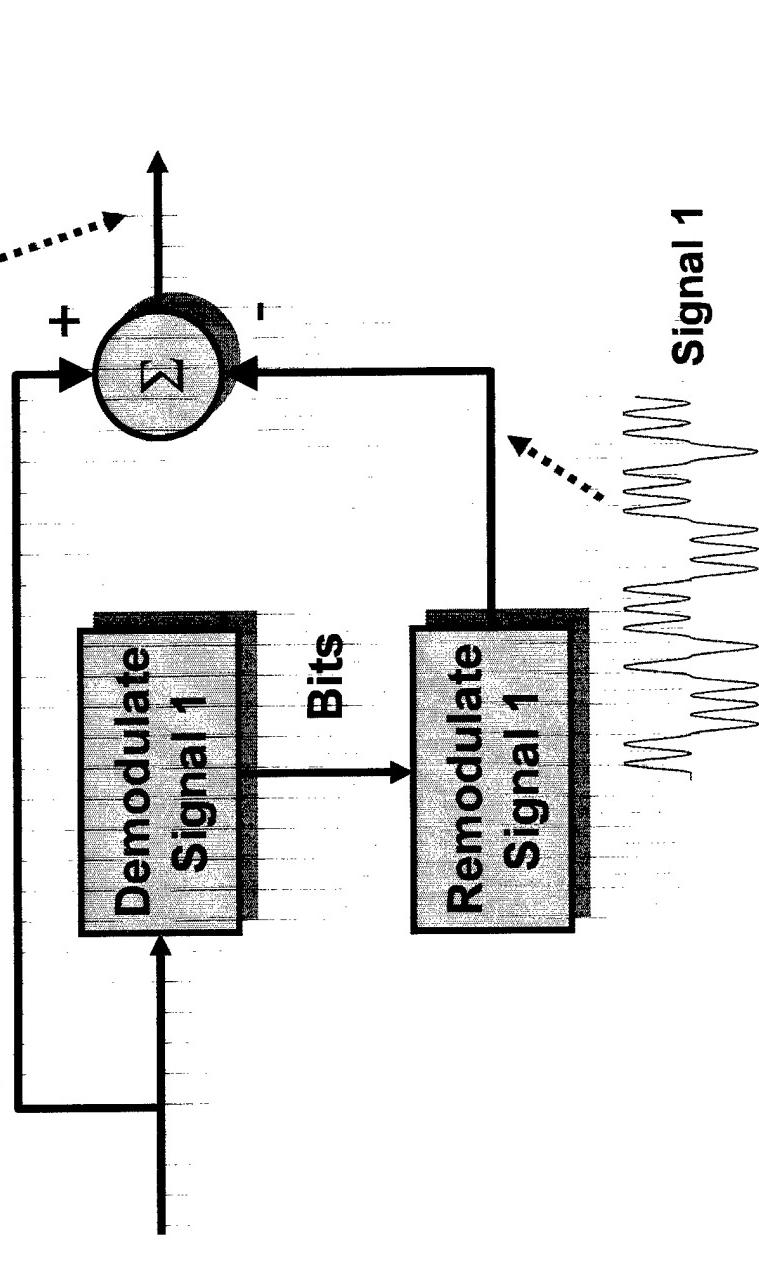


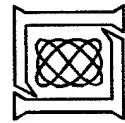


Notional Multiuser Detection



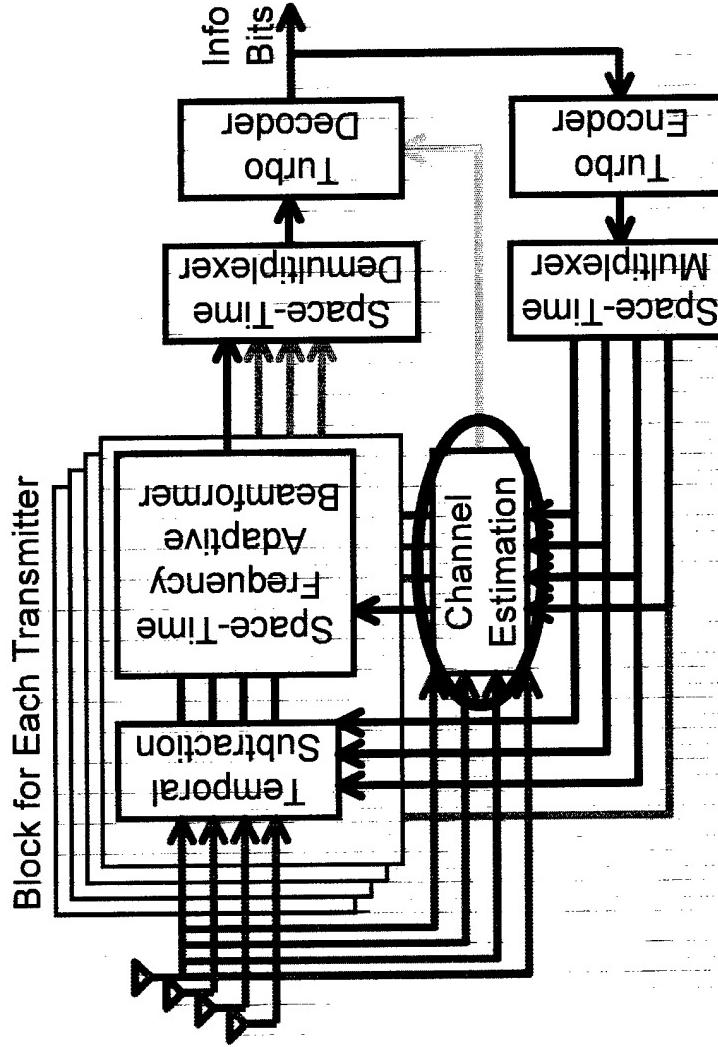
Signal 1 + Signal 2

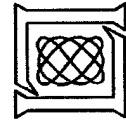




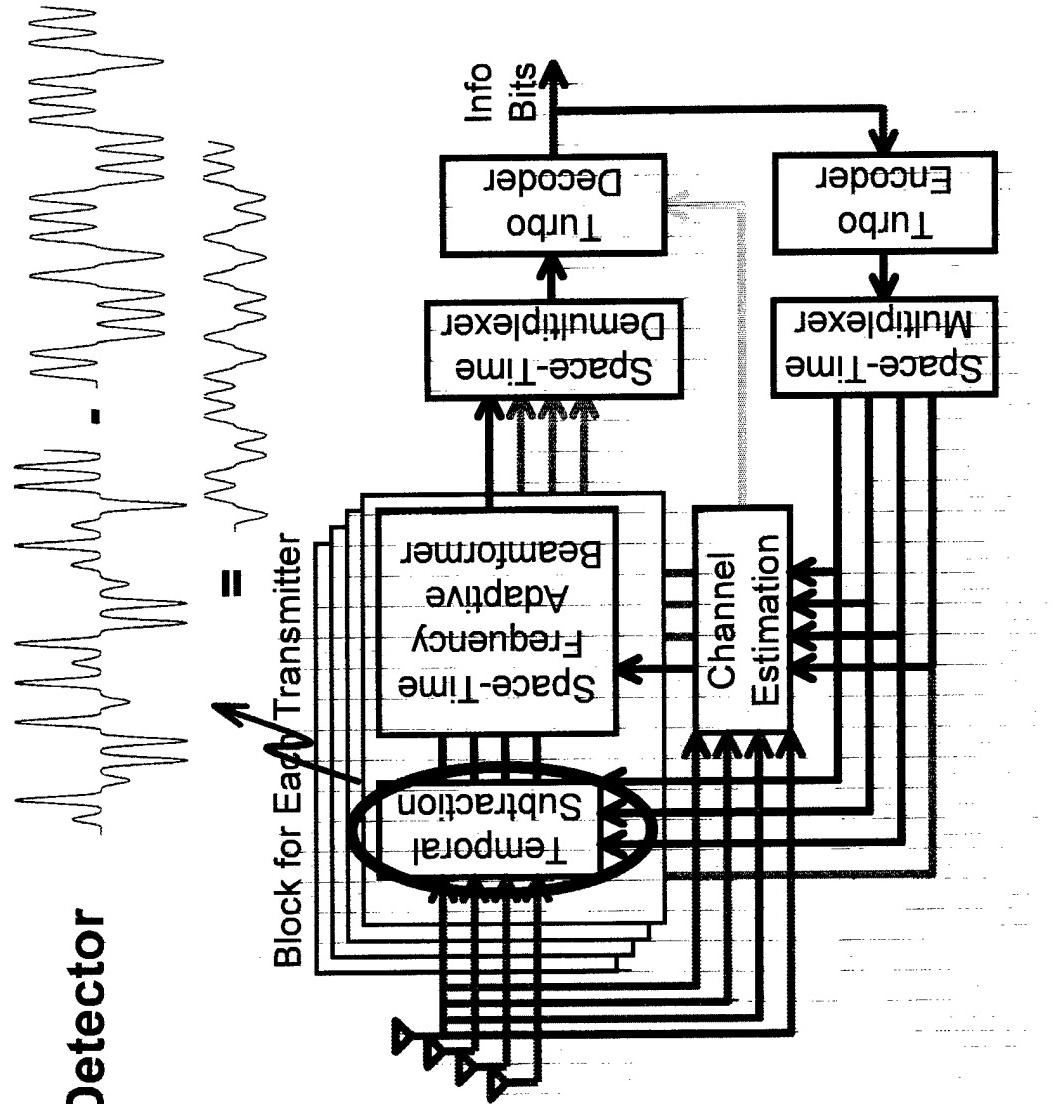
MCMUD for Space-Time Turbo Code

- Multichannel Multiuser Detector (MCMUD, pat. pending)
- Iterative decoder
- Channel estimate
 - Training-based
 - Data-directed
- Estimation subtraction (multiuser detection)
- Space-time-frequency adaptive beamformers

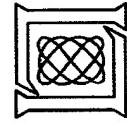




MCMUD for Space-Time Turbo Code

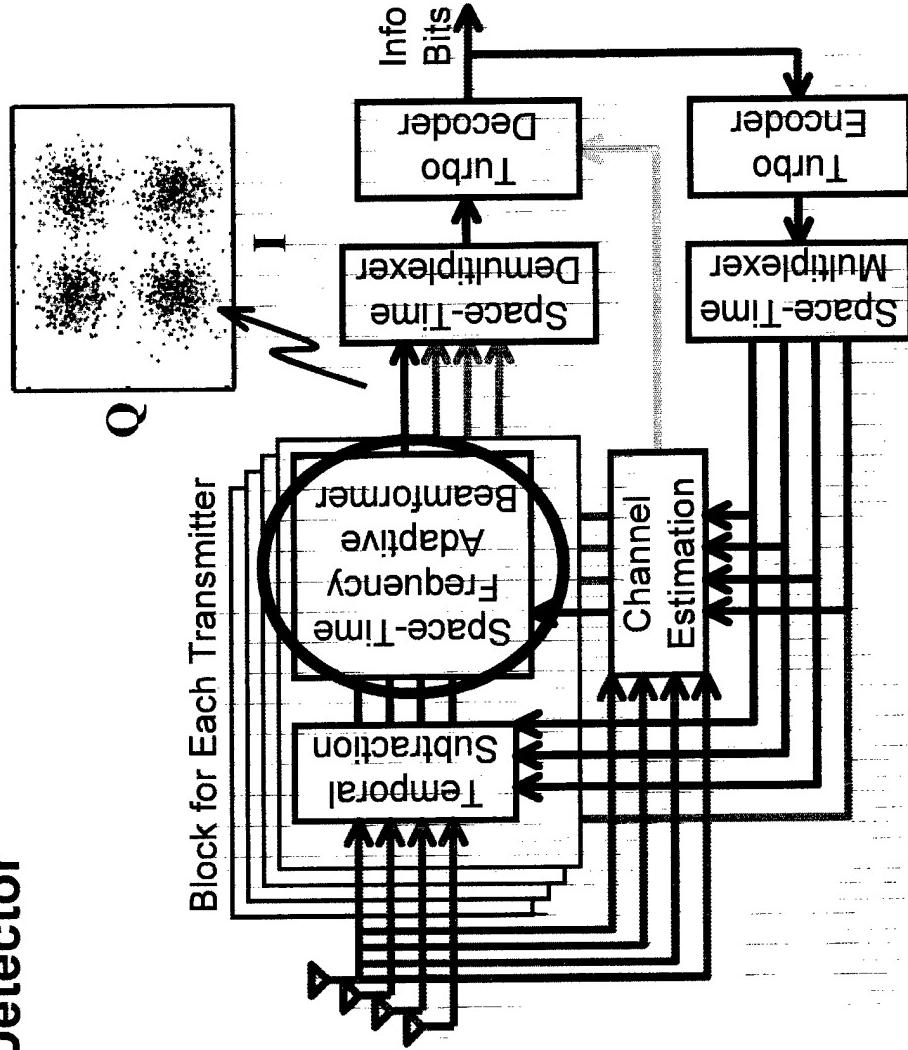


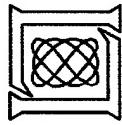
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MCMUD for Space-Time Turbo Code

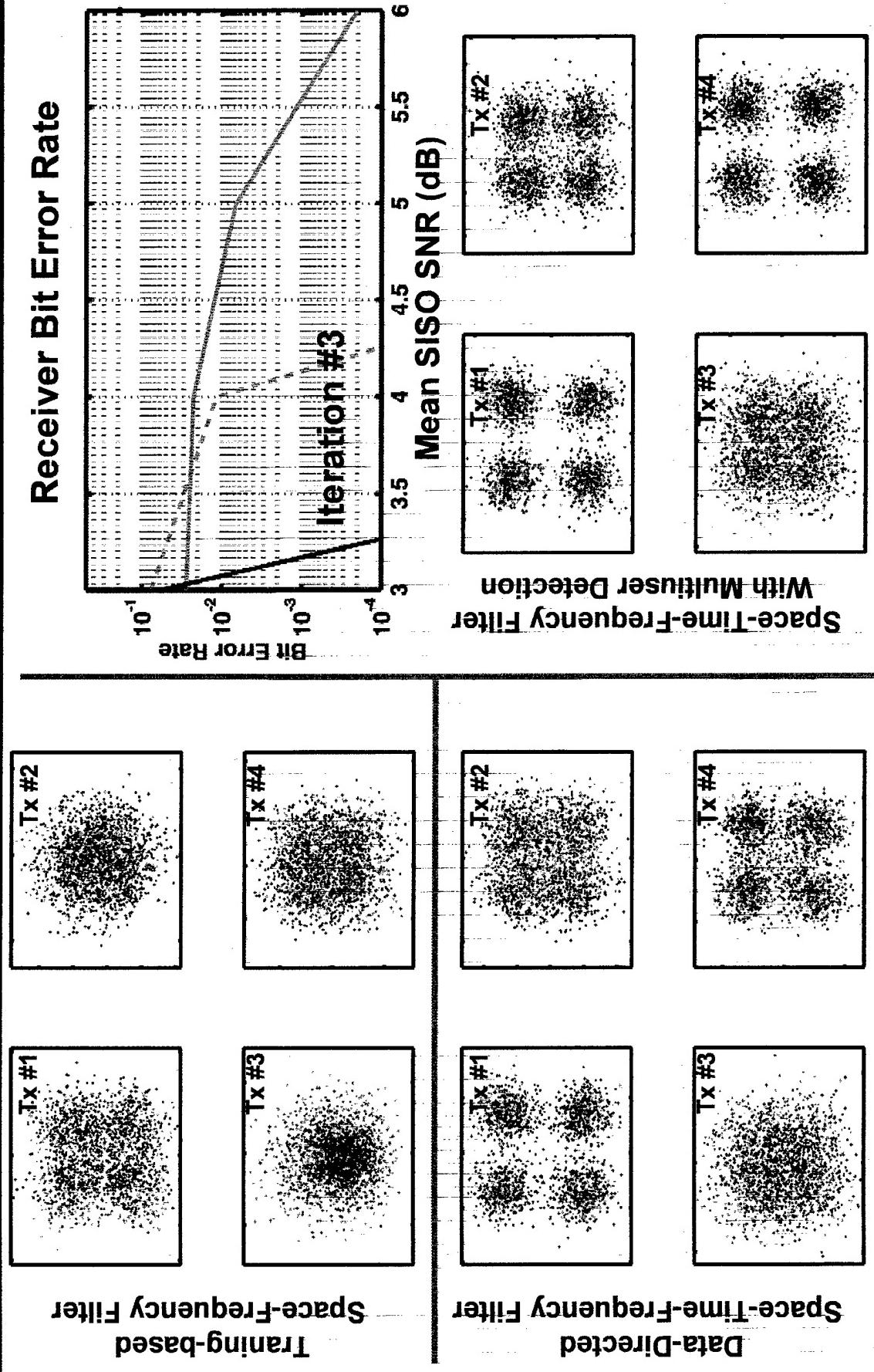
- Multichannel Multiuser Detector
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 - Training-based
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- Estimation subtraction
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- Space-time-frequency
adaptive beamformers

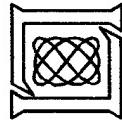




Experimental Results

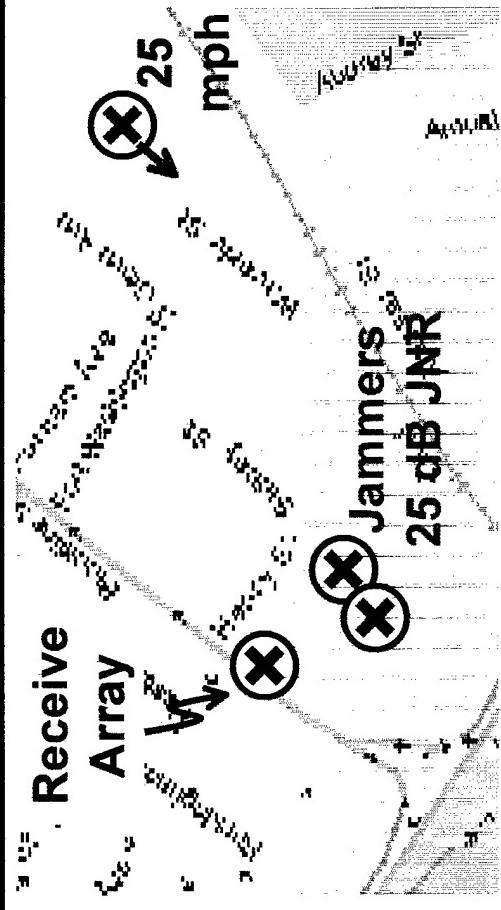
Successive MCMUD Iterations





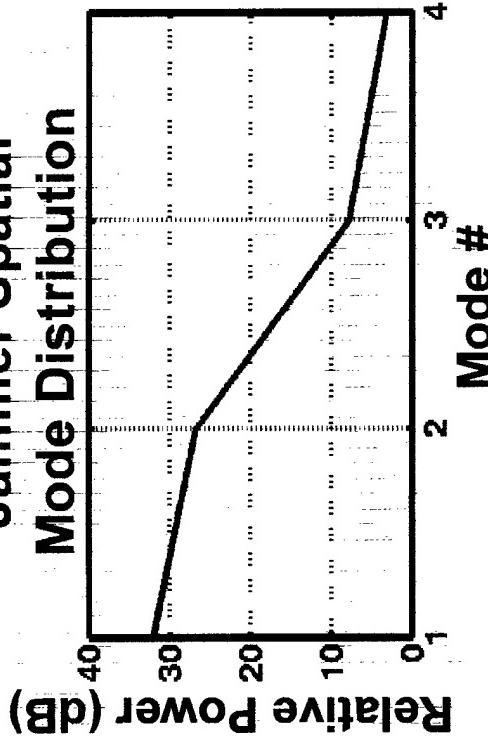
4x4 MIMO Performance

Motion, Jammers, and LO Errors

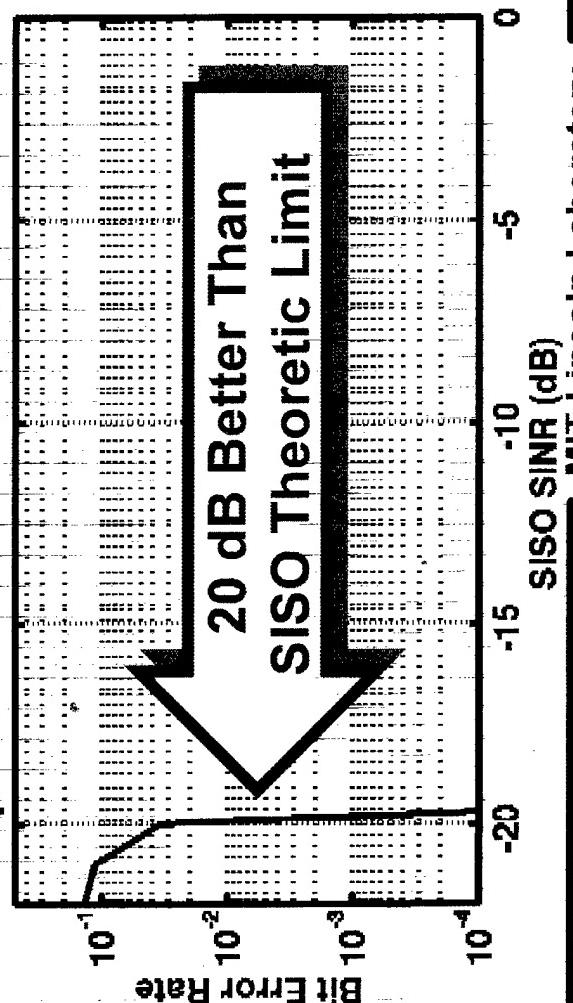


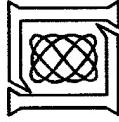
- 2 Noise Jammers (25 dB JNR)
- Moving transmitter (25 mph)
- Artificial relative local oscillator error (± 80 Hz)
- Error-free 2b/s/Hz data-link
- Near performance of jammer-free environment!

Jammer Spatial Mode Distribution



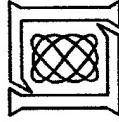
Experimental MIMO Performance





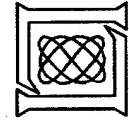
Summary

- MIMO provides robust communication links
- New receiver design concepts (MCMUD) enable communication in complicated environments
- Demonstrated dramatic performance advantages using experimental data
- MCMUD enables coherent use of ad hoc distributed networks for MIMO communication



Acknowledgements

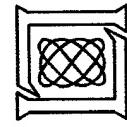
- MIT Lincoln Laboratory New Technology Initiative Board
- Experiment team
 - Sean Tobin, Jeff Nowak, Lee Duter, John Mann, Bob Downing, Peter Priestner, Bob Devine, Tony Tavilla, Andy McKellips, Gary Hatke
 - Code, algorithm and experiment design
 - Keith Forsythe, Peter Wu, Ali Yegulalp
 - Analysis support
 - Amanda Chan
- Students
 - Nick Chang (U. Mich), Naveen Sunkavally (MIT)



Backup Slides

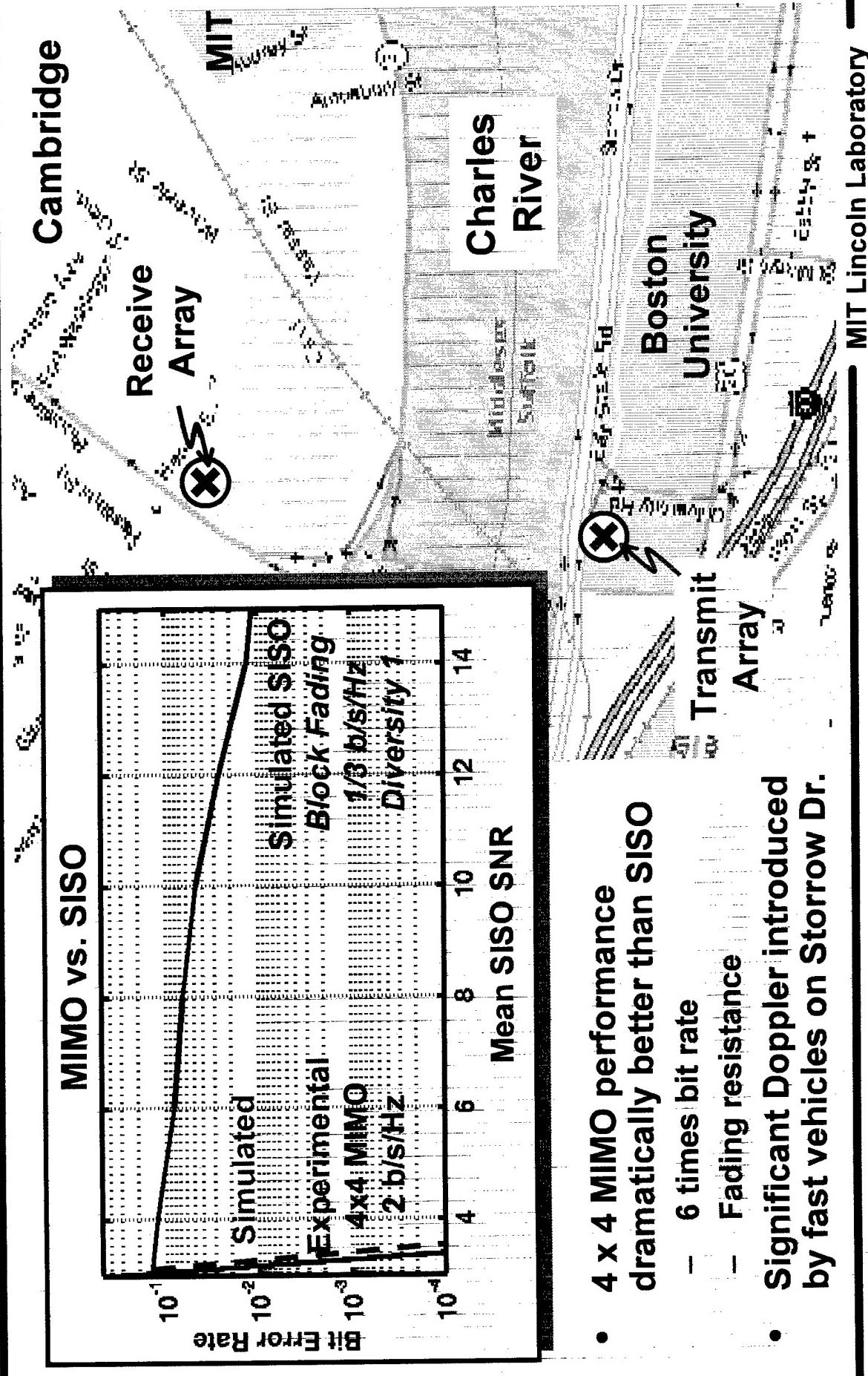
Advanced Shoe-Phone Technology

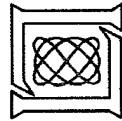




MIMO Ground-to-Ground Example

Non-Line-Of-Sight





Space-Time Codes Used in Experiment

4 Transmitters

- Alamouti (2 Tx), $\eta = 2$
- Block, $\eta = 3$
- Turbo, $\eta = 2$
- Turbo, $\eta = 4$
- CDMA, $\eta = 12/256$
- LDPC, $\eta = 1$
- LDPC, $\eta = 2$
- Trellis (Chen), $\eta = 2$

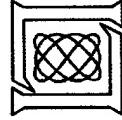
8 Transmitters

- Channel probe
- 2+2+2+2 Trellis, $\eta = 6$
- Block, $\eta = 3$
- Turbo, $\eta = 4$
- Turbo, $\eta = 8$
- CDMA, $\eta = 18/256$
- CDMA, $\eta = 20/256$
- LDPC, $\eta = 2$

Space-Time Code Source

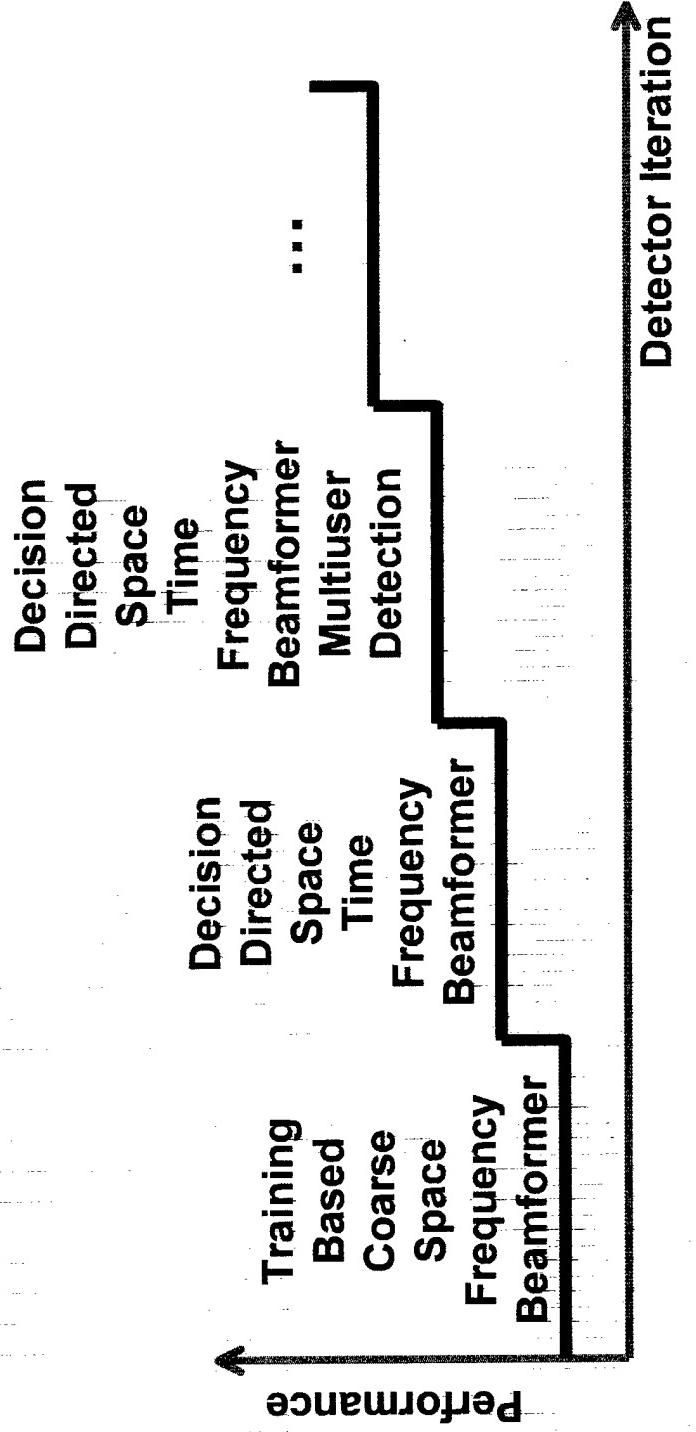
- New Designs
- Provided by campus
- Literature

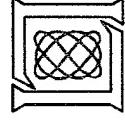
η – Spectral Efficiency (b/s/Hz)



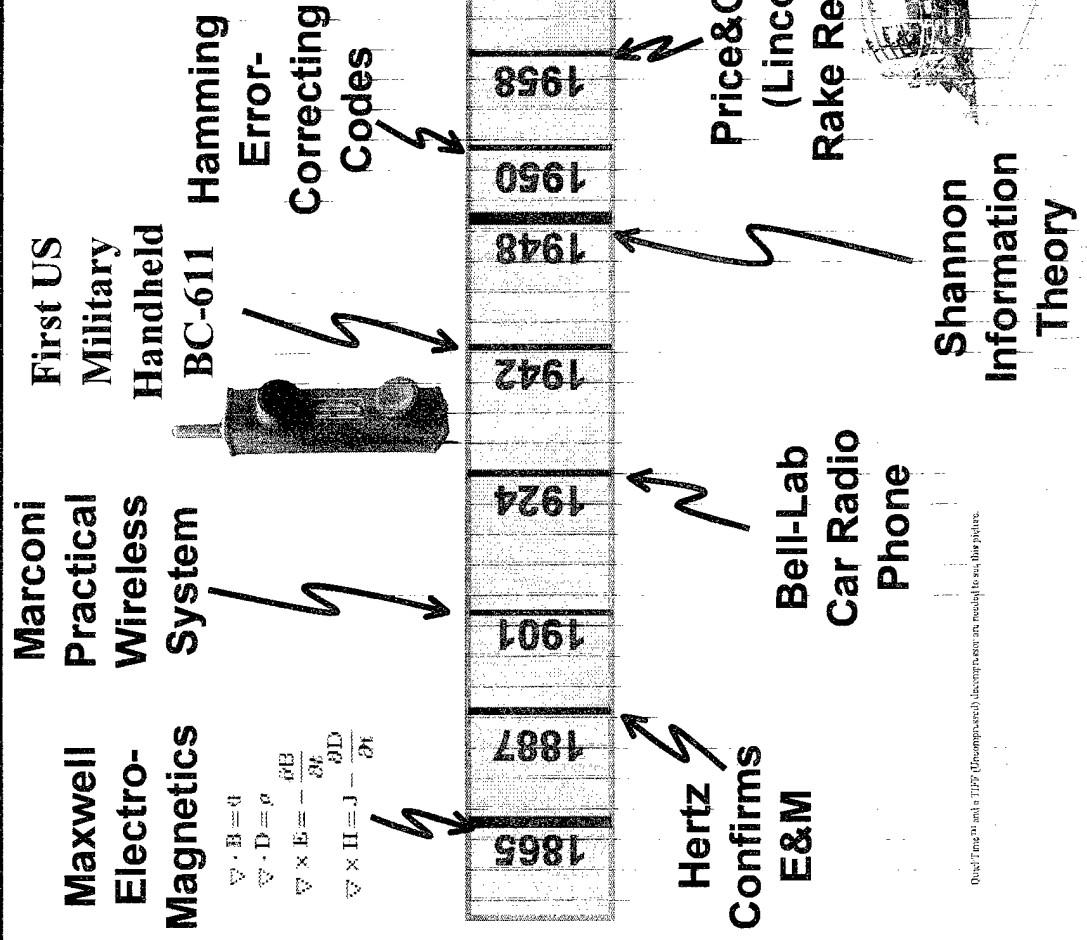
MCMUD Detector Progressive Complexity

- Joint channel and data estimation
- First iteration access to limited training data or channel estimate from previous frame
- Increase detector complexity with iteration
 - Increase number of turbo iterations with number of detector iterations

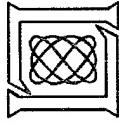




History of Wireless Communication

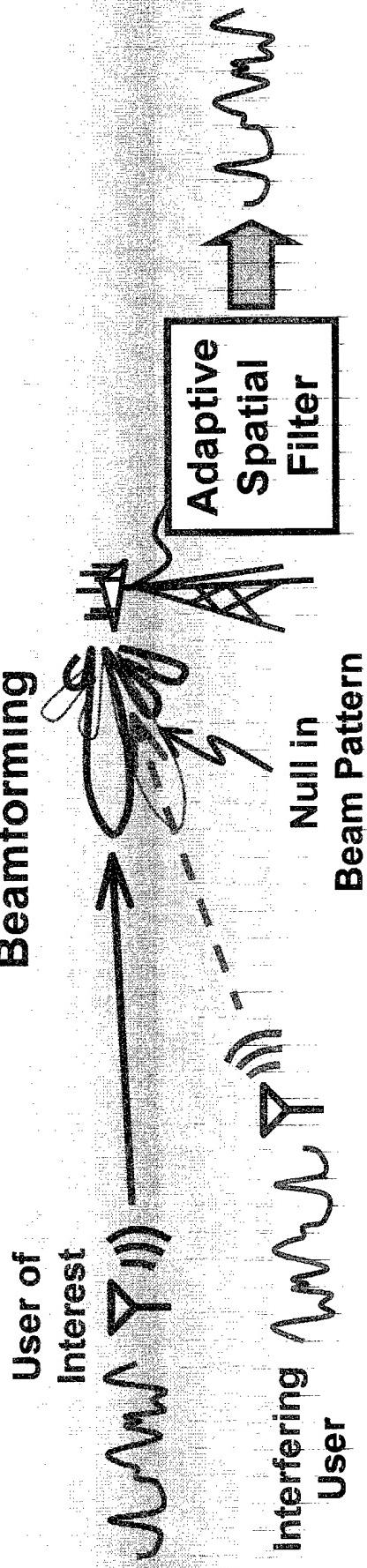


$$C = \log_2 (1 + SNR)$$

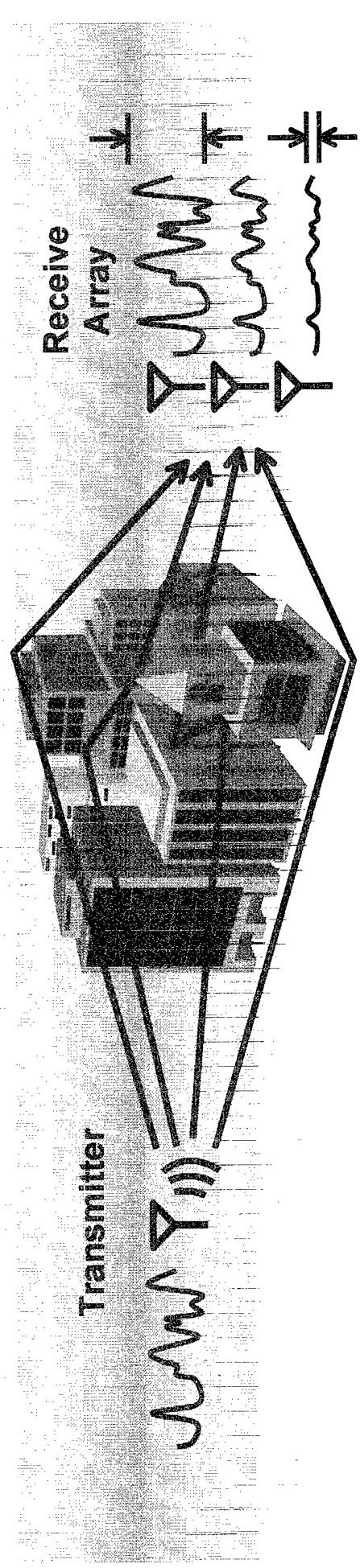


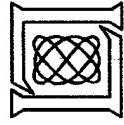
Important Antenna Array Concepts

Adaptive Spatial Beamforming



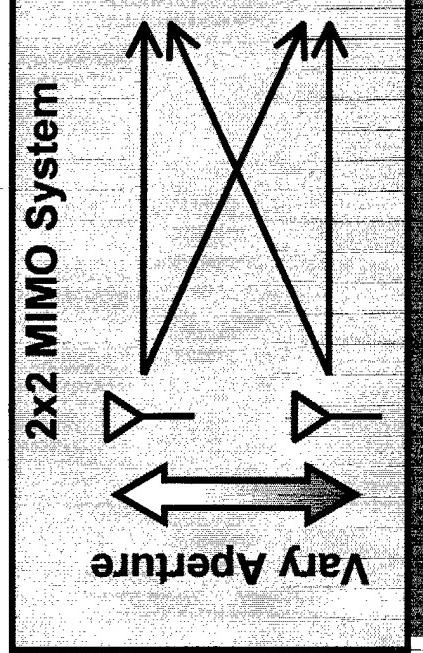
Diversity



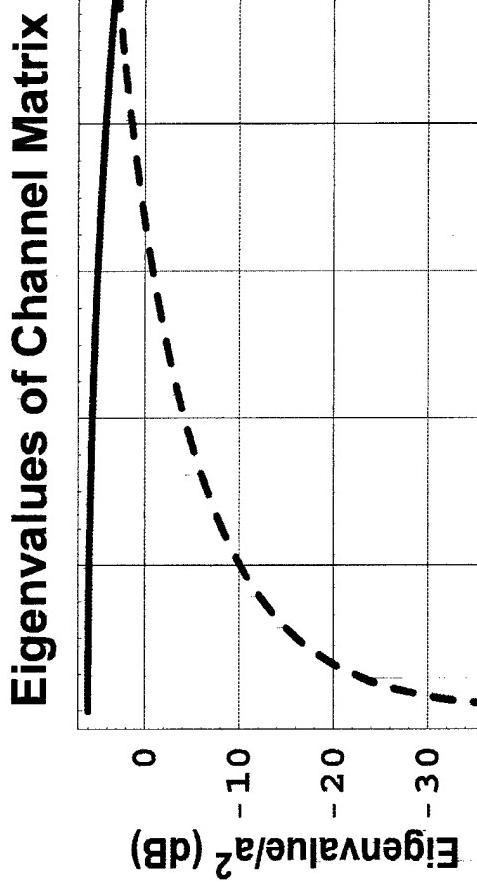


The Channel Matrix

A Toy Model



- Toy MIMO channel model
 - 2x2
 - line of sight
- Resolving individual antennas increases eigenvalue
- MIMO systems in real environments employ scatterers to increase effective aperture



Generalized Beamwidth Separation

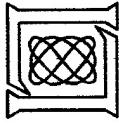
$$b = \frac{2}{\pi} \arccos \left| \frac{\mathbf{h}_1^\dagger \mathbf{h}_2}{\|\mathbf{h}_1\| \|\mathbf{h}_2\|} \right|$$

Channel Matrix, $\mathbf{H} = \begin{pmatrix} \mathbf{h}_1 & \mathbf{h}_2 \end{pmatrix}$

$$= 2 \alpha \begin{pmatrix} \mathbf{v}_1 & \mathbf{v}_2 \end{pmatrix}$$

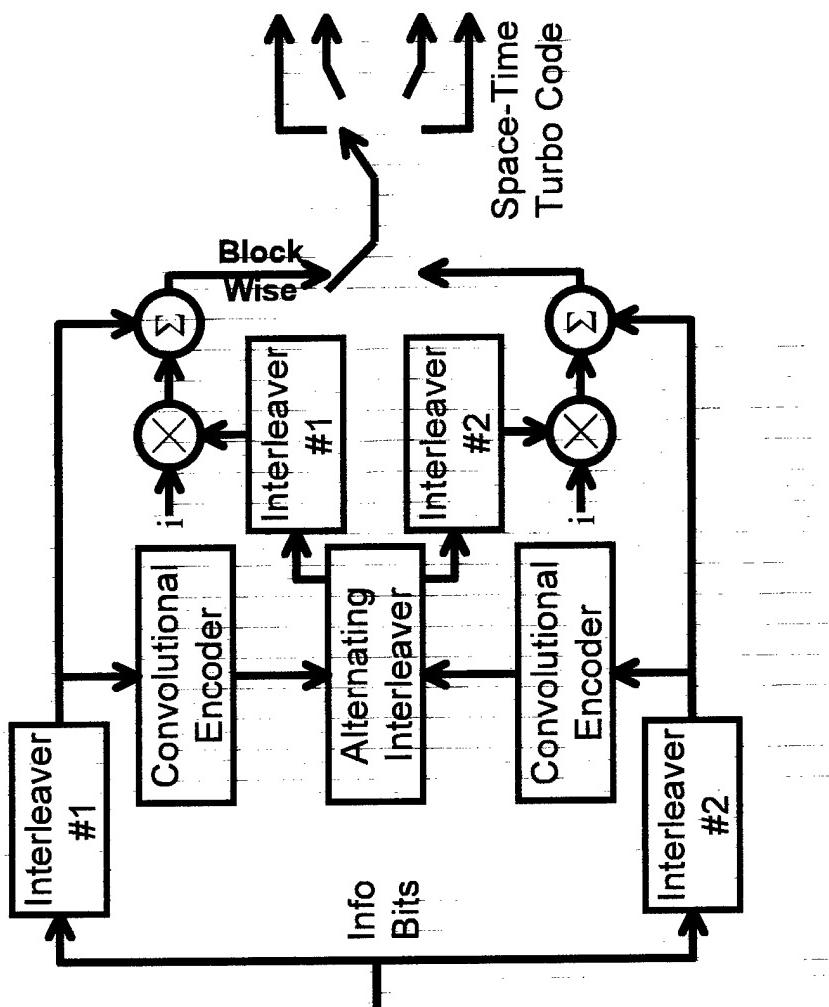
Unit norm
steering vector

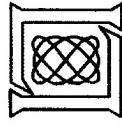
MIT Lincoln Laboratory



Space-Time Turbo Code

- Block diagram for space-time turbo code
- Rate 2 b/s/Hz
- 123 kChip/s
- 4 Tx antennas
- 4096 bit interleavers
- QPSK constellation
- Optional training data





Uncooperative External Interference

Effective Loss of Complexity

- Uncooperative interference is equivalent to spatially correlated noise
- Covariance of interference plus noise
- Maximize capacity by “decorrelating” channel matrix with respect to interference
 $\tilde{\mathbf{H}} = \mathbf{R}^{-1/2} \mathbf{H}$
- Estimate $\tilde{\mathbf{P}}$ using new $\tilde{\mathbf{H}}$
- Modes near interference energy become less useful
- Effectively reduces the environmental complexity

Channel Capacity in Interference

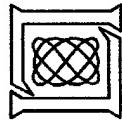
Informed Transmitter (IT)

$$\tilde{C}_{IT} = \max_{tr\{\tilde{\mathbf{P}}\} = P_o} \log_2 |\mathbf{I} + \tilde{\mathbf{H}} \tilde{\mathbf{P}} \tilde{\mathbf{H}}^\dagger|$$

Noise-Normalized
Transmit
Covariance
Matrix
Interference Whitened
Channel Matrix

Uninformed Transmitter (UT)

$$\tilde{C}_{UT} = \log_2 \left| \mathbf{I} + \frac{P_o}{n_{Tx}} \tilde{\mathbf{H}} \tilde{\mathbf{H}}^\dagger \right|$$



The Channel Matrix

- Channel matrix, H , contains complex attenuation between each transmit and receive antenna
- Large channel eigenvalues of HH^\dagger are useful

